Considering adaptation and the 'function' of traits in the classroom, using wiki tools

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ABSTRACT
The conceptual understanding of the process of adaptation (whereby a population becomes better suited to its environment over evolutionary time) is acknowledged to be a difficult one. Many studies have shown that there is an inherent misunderstanding of the term, which is often related to the learner adopting the common rather than biological usage of the term in the learner's language. However, understanding adaptation is essential to understanding evolution, and learners need to be encouraged to understand how to relate hypotheses of the 'function' of a trait shown by an individual with the environment in which the individual lives. Here, I describe a practical which encourages a class of learners to create their own organisms, through a series of steps by which they create functional explanations of morphology and behaviour. Using a branching process whereby groups of students are split into smaller and smaller subgroups, an artificial phylogeny is created. A wiki system is then used to emphasise how individual species and groups of species are related. The relationship of this practical to problems of tree-thinking is discussed.

KEYWORDS
functional explanations, adaptation, tree-thinking, trait, speciation, group-sourcing, wiki, web 2.0

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INTRODUCTION

Adaptation is the process by which a species adjusts to the conditions of its environment over evolutionary time, as individuals with traits that give them some sort of an advantage become more common within the population through some selective process. Those traits that enhance the fitness (as measured by the survival or reproductive success) of an individual are adaptations (Gregory 2009 gives an excellent overview of some of the common misunderstandings about the concept of adaptation). From a scientific perspective, being able to explain how a particular trait of an organism (be it morphological, developmental, behavioural, or some aspect of its life history) affects the fitness of an individual involves formulating hypotheses about the 'function' of the trait. The 'function' or adaptive value of a trait refers to the way in which the trait affects the organism's fitness, in comparison to how other possible traits could perform in the organism's current environment. A huge amount of scientific research, particularly in the fields of behavioural and evolutionary ecology, has focussed on testing these functional hypotheses (Danchin et al. 2008; Fox & Westneat 2010; Fox et al. 2001). For example, the number of eggs laid by a bird within a single clutch differs between species. Various explanations relating clutch size to the reproductive biology of a species, the environment in which it lives, and the constraints imposed by its evolutionary history have been proposed and explored by many scientific workers, encompassing descriptive (e.g. Lack 1947; Moreau 1944), theoretical (e.g. Charnov & Krebs 1974; Cody 1966; Lack 1968; McNamara et al. 2008), manipulative (e.g. Murphy 2000; Slagsvold & Lifjeld 1988; Williams 2001; Ydenberg & Bertram 1989) and comparative (e.g. Bennett & Owens 2002; Jetz et al. 2008) techniques. This demonstrates that functional explanations for adaptations are accessible to scientific testing. As Sloan Wilson (2005) notes, correctly understanding adaptation is a cornerstone of understanding evolution. Learners should be able to hypothesise about the function of traits in organisms, and then extend this to understand why sister species may share some traits but show great differences in others.

However, misunderstandings about the nature of 'adaptations' are common in students encountering evolution for the first time. To effectively teach the subject, we need to initially address conceptual misunderstandings that are inherent in the learners, and then design our teaching methods to promote conceptual change (Carey 2000; Demastes et al. 1995). One of the initial conceptual problems that needs to be addressed when teaching evolution is the perception of adaptation (and consequently the evolutionary process itself) as 'need-driven transformation' (Rudolph & Stewart 1998). Here, an organism is wrongly seen as being able to address problems it can face in the environment, by altering itself in such a way that can be passed onto its offspring. Variations on this incorrect definition of adaptation are recorded at many educational levels in many countries (Bizzo 1994; Enzel Clough & Wood-Robinson 1985; Ferrari & Chi 1998; Geraedts & Boersma 2006; Gregory 2009; Kampourakis & Zogza 2008, 2009; Nehm & Reilly 2007; Palmer 1996; Prinou et al. 2008; Settlage 1994; Tidon & Lewontin 2004; Zuzovsky 1994). At the same time, students have problems differentiating between the noun and verb versions of the word 'adaptation' (Lucas 1971; van Dijk & Reydon 2010), meaning that careful use of language is important in teaching evolution (Alters & Nelson 2002; Smith et al. 1995; Tidon & Lewontin 2004). We therefore need to take great care in how we present the concept of adaptation to learners. On the one hand, it is essential that we encourage free thinking and speculation about the biological function of a trait in relation to the organism's environment. But, on the other hand, we must be careful to emphasise the evolutionary history that led to the trait being selected for within the current population.

Here, I outline an 'active learning' practical aimed at undergraduate students taking an introductory course in evolution, which involves the learners with explaining how organisms have evolved in relation to specific aspects of their environment. The approach uses a similar 'improvisation' feel to the practical described by Guidetti et al. (2007), where the functional basis of an adaptation and the environmental or life history pressures that shaped it are considered together by the student. In this practical, the process of constructing a list of adaptations specific to each student's individual species starts as a collaborative process where the class agree together on a set of characteristics shared by all the organisms. As the practical progresses, the work conducted by each student becomes much more personal as the class is gradually split into groups containing fewer and fewer students, where the members of each group agree on independent adaptations and environmental characteristics. The gradual splitting of the class creates a hierarchical structure which is analogous to an evolutionary tree, but which may be more familiar to the students as the process by which files are organised on a computer. Playing on this analogy, the practical makes use of wiki tools to quickly create a simple, hierarchically-arranged website of the students' work within the practical, giving the students an immediate interactive tool for exploring the relationships between their own 'species' and those of their classmates.

PRACTICAL DETAILS

This practical uses a mixture of class discussion, paper-based group work, and individual computer work using a wiki editor. Wiki tools are becoming increasingly important as an educational tool (Godwin-Jones 2003; Konieczny 2007; Neumann & Hood 2009; Parker & Chao 2007; Ruth & Houghton 2009; Schwartz et al. 2004). These collaborative, web-based tools offer a simple means of letting multiple users simultaneously create, annotate and edit web pages ('crowd-sourcing'), usually with little or no previous experience of the tool. This allows a large number of web pages to be created quickly and simultaneously, without much technical groundwork by the class leader before the practical has commenced.

Although this practical could feasibly be run with pencil, paper, and a little ingenuity, using a wiki tool makes it much easier for the students to take home the work produced in class for further exploration. I do not give exact details of which wiki editor to use, as the technology available is likely to change fast, but a rapidly expanding number of editors (some of which are free) are available and relatively easy to get hold of. I would however advise careful choice of your editor, if you have the luxury of choice. Exact requirements will depend upon the size and learning requirements of the class (but a number of issues should be taken into consideration, as described in appendix 1). Incorporating the use of wiki technology into large-group classwork also serves as a useful demonstration to the class of how wiki material that they encounter may have been generated, and it may be useful to give some discussion to where they may have encountered these resources before, and who has been creating the material (the uses and abuses of *Wikipedia* by students are well documented – see Santana & Wood 2009 for an overview of some of the less frequently discussed problems, and Page *in press* for discussion of how *Wikipedia* may be influencing taxonomic thinking).

At the beginning of the practical session, prior to the material described below, it is advisable to set a few warm-up exercises for the students to allow them to become familiar with the wiki editor. As a pre-requisite for the practical, the students should be able to create their own pages, and then experiment with the different forms of text they can create, as well as work out how to create links to both external pages and pages being created concurrently by their classmates within the class wiki. This work should take no more than ten minutes.

<u>PART 1: group discussion work, requiring pencil and worksheet.</u>

The following outline is for an ideal 32 student practical session, giving six 'taxonomic' levels to the work. Taxonomic levels can be added or removed if the class size is significantly larger or smaller, and the dichotomous branching used in figure 1*a* can be altered to give polytomous branches (with students split into three or more groups, rather than the two at each stage in figure 1*a*).

1a: Climate and broader details of habitat (c. 10 minutes).

The aim of this first section is to decide upon a broad environmental type within which to frame the exercise. It is advisable to pick an environment with which the students are familiar, and encourage them to think about what may happen if extreme environmental changes occur, such as through climate change processes. For example, the region of the UK I teach in has a wet, maritime climate, and flooding is a newsworthy concern throughout the year. Discussing how climate change will affect local geography and seasonal conditions with the students easily leads into discussion of local climate history (touching on recent glaciation and the effects of changing sea levels on local marshes and fenland), which can then be used to inform a group-decision on a suitably extreme set of conditions. Having decided upon the conditions, a short (twenty or so words) summary is decided upon as a group, and written at the top of the worksheets (see the example provided in Supplementary Material 1).

This section works principally as a tutor-led question and answer session, and it is advisable that the class leader has some discussion points prepared, and a fully worked-out fall-back example lined up if the students are initially reticent to discuss details.

1b: First group division (c. 10 minutes).

The class is now split into two groups (which would contain sixteen students each if the class size was initially 32). Name the two groups with an arbitrary taxon code (B1 and B2 are used here), and get them to note this on their worksheet (in the 'taxon' column of the worksheet given in Supplementary Material 1). It is also advisable to sketch and label this splitting (and the further splits, as in figure 1*a*) in a visible place such as a whiteboard, so that the branching process can easily be reconstructed later in the session.

Having physically settled as groups, the class leader now explains that the two groups should act independently of each other. Each group is asked to identify a range of characteristics related to a specific aspect of the organism's biology (e.g. morphology, breeding system, behaviour) that would enable an organism to successfully survive within the environment decided upon as a class. Having identified and discussed a number of characters, they should then pick one for their group. It is recommended that this is done twice, to agree on two separate biological characteristics for the group. For example, one of these two characteristics could be a morphological character, and the other, some life history character (or, if the students haven't considered the concept of life histories in detail, fix on something more detailed: in the worksheet given as Supplementary Material 1, a description of the organism's 'reproductive system' is specified instead). Therefore, as a group, the students have to agree upon two characteristics to be used within their environment, and also agree upon a standardised, short (e.g. twenty word) piece of text that describes each of these characteristics, which is written somewhere visible to all the group's members (such as on a whiteboard or a large sheet of paper), and then copied by all the students onto their worksheets.

During this stage, it is advisable to talk separately with each of the groups, and discuss their ideas about the sorts of characteristics that may be suitable for the environment initially proposed as a class. Rather than fixating on one set of characteristics right at the beginning, the students should be encouraged to come up with a selection of possible characteristics, and then choose their favourite set.

Care must also be taken in the language used in setting work here and in the following sections, to avoid misconceptions thrown up by ambiguous wording. The students are being asked to 'choose' an adaptation which is 'suitable' for the environmental conditions. Talking about what adaptation an organism "should have" to be able to survive in a particular environment is potentially dangerous, and care should be taken to highlight the process of adaptation through selection, avoiding adaptation being interpreted as 'need-driven' change.

1c, 1d and 1e: Further sub-divisions of the group (5-10 minutes each)

Each of two groups is then split into two smaller groups (of eight students each, if the class size was initially 32 students), and each of the groups is given an arbitrary taxon code (either C1, C2, C3, or C4, as given in figure 1*a*). Again, the students in each group should be encouraged to act independently of all the other groups in the class, where the only thing shared is the set of characteristics that has already been decided upon and entered onto the worksheet. A similar exercise as in section 1b is then conducted, with a different set of characteristics to decide upon within the group. For example (given in Supplementary Material 1), I ask the groups to first decide upon more specific details of the habitat their organism is found in, and then, having generated a number of morphological characteristics that may be suitable to that habitat, to pick one of these for their group. It should be emphasised to the groups that these new details have to fit with the details already decided upon in sections 1a and 1b. Once group decisions have been made and noted, the groups are given a few more minutes to agree upon a name for their type of organism, which is noted on the sheets.

Following a suitable length of discussion time, and an enforced period to generate, agree upon and write down group definitions of characteristics, each group is then split, and this section is repeated a further two times (for taxonomic levels D and E of figure 1*a*), leading to sixteen pairs of students (if the initial class size was 32). At each stage, a name for each of the resulting groups of animals should be decided upon by the groups. It is recommended that rules aren't laid down beforehand on how names should change between taxonomic levels (see the discussion).

PART 2: Independent work (10-15 minutes)

The students are now told to decide upon a final characteristic of their organism, which fits with the previous characters they have written on their worksheets. This character should be decided upon independently of the decisions made by anyone else in the class. They are then asked to move to the computers, and create a short description of the natural history of their organism on a newly created page within the class wiki. At the same time, the student should draw (and briefly annotate) a sketch of their organism. If the drawings are made on a separate sheet of paper, they can be collected by the session tutor, scanned, and the resulting images can be electronically redistributed to the students to add into their wiki page (this may be possible during the class session, if there are class helpers available).

PART 3. Moving back up the tree (15-20 minutes)

Having written individual pages describing the branch-ends of the tree, the aim is now to consolidate the relationships between organisms. The students should be asked to form back into the groups they were in at stage 1c of the practical (in a class of 32 students, this is the stage at which there were four groups containing eight students). Within their groups, get them to draw the branching structure that shows the relationship of their created species (e.g. the sub-tree starting at node C1 in figure 1*a*). As a group, they should decide on the names to give their various nodes (e.g. for the sub-tree starting at C1 in figure 1*a*, the branching points labelled C1, D1, D2, E1, E2, E3 and E4). Pages should then be created for each of these nodes, containing a description of the common characteristics of all the species that branch from that node (with links to the next taxonomic groups that branch from the node), as well as details of the taxon that the current node is 'descended' from. So, for example, the page describing node E3 will contain information about the characteristics specific to E3, as well as links to the pages for species F5 and F6, and a link to the parent node D2. It is inevitable that there will be more students than pages to create, and therefore at least one member of the group should be designated as a 'go-between', involved with co-ordinating the pages being created by the group, and higher level pages that should be created by the class tutor (corresponding to the higher nodes A1, B1 and B2 in figure 1*a*) to bring all the class work together.

DISCUSSION, AND POST-PRACTICAL WORK

This practical gives a short introduction to thinking about the relationship between biological adaptations and their environment. At the same time, emphasis can also be placed upon how these adaptations can differ between closely-related species, which can be done in post-practical discussion by talking about similarities and difference between closely-related species within the class tree. Follow-up work could involve smaller groups of the students creating similar, smaller wiki-based taxonomies of existing species (e.g. real animals), or discussion of how the work described in the practical relates to the construction of evolutionary trees. Teaching students to correctly interpret evolutionary trees is a frequently-encountered problem (Baum et al. 2005; Meir et al. 2007; O'Hara 1997; Perry et al. 2008). Several educational techniques are being devised to address these problems (Baum et al. 2005; Gregory 2008; Smith & Cheruvelil 2009), and the practical developed here offers an additional approach. For example, in this practical, the students are constructing a phylogenetic tree that doesn't come with any preconceptions about whether branch lengths represent time, as the only assumption made during the practical is that the branching represents a level of relatedness between different groups of organisms. Post-practical discussion could therefore also turn to questions relating to 'tree-thinking' (Baum et al. 2005; Omland et al. 2008).

The taxonomy created also involves some degree of decision-making by the students about how their species and higher taxonomic orders are named, and it is recommended that the tutor does not impose any rules at the outset on how names should change between levels. It is feasible that a 'phylogenetic' form of taxonomic branching of the names could occur (with a 'species' name containing elements of the 'genus', 'family', etc. within it), but it is more likely that there will be some loss, redundancy of terms, and renaming between levels. How things have been named can then form part of the class discussion: as well as discussing the binomial system and how higher taxa are named, mention can also be made of folk-taxonomy and 'common' names (e.g. Berlin 1992; Berlin et al. 1973). This problem is probably best discussed near the end of the practical, when the class is deciding upon the names of the highest taxonomic levels. Post-practical, it is worthwhile recording the names given by the class to the different nodes, as an exploration of the group decisions about naming taxa by a collection of individuals naïve to standard taxonomic practices may give us interesting insights into potential student understanding and confusion about taxonomy.

In generating a class taxonomy similar to that illustrated in figure 1*a*, it could be wrongly construed by the students that ancestral populations always give rise to derived, 'newer' populations (e.g. 'ancestor' E12 gives rise to 'descendents' F23 and F24): adaptive radiation may equally see 'ancestral' lineages surviving at the same time as more recently evolved ones. To avoid any misconception, the instructor could easily lead discussion by adding in one or two species which haven't undergone the same degree of adaptive radiation as those generated by the class (in figure 1*b*, illustrated by N1 and N2).

The tree constructed within this exercise could also be used to explore ancestral state reconstruction, which would further emphasise the manner in which the tree was constructed. It is feasible that species at the tips of the trees may have similar adaptations that have 'evolved' more than once due to individual students independently deciding on similar traits (*e.g.* species F9, F22 and F32 could all independently end up with prehensile tails), which would be analogous to a homoplasy. A homoplasy is an apparent similarity which comes about through processes such as convergent or parallel evolution, or the reversal to an ancestral condition, and can pose a problem when trying to reconstruct phylogenies (Wake 1991). From the history presented by the phylogeny, the decision about what happens at each bifurcation could be considered as the point at which there is a known historical change in an ancestral state. By using simple phylogenetic reconstruction techniques such as maximum parsimony, the students could explore whether these techniques are able to accurately reconstruct the historical processes if only the information about the traits carried by the species at the tips of the tree is used. For a good overview of techniques for reconstructing ancestral states, see Omland et al. (2008). If there is an emphasis on phylogenetic techniques within the curriculum, it may also be possible for the instructor or students to consider how different species could perhaps be lumped together as paraphyletic or polyphyletic groups.

The practical described here gives a new method for encouraging students to think about the 'function' of adaptations, using an increasingly common piece of educational technology. In generating candidate strategies and traits at each of the 'branching' stages of the practical and then deciding upon which of these candidates is used by the group, the students are encouraged to think about functional explanations for their selected adaptations. As described in the introduction, care needs to be taken to emphasise the biological basis of adaptations, and the students also need to be taught what an adaptation isn't (Gregory 2009). Furthermore, care should be taken to remind the students of both the selective processes for adaptations, and mechanisms that generate them in the first place (which will doubtlessly tie in with more traditional lecture and course work within the course). The high level of interactivity, coupled with the ability of the students to review each other's work (which also allows them to easily access the work at home, to explore at their own leisure), ultimately means that a class can create a large number of different organisms and intimately explore the relationships between them, by analogy of a technology that they are likely to have a thorough understanding of.

APPENDIX 1 – RECOMMENDATIONS FOR CHOOSING A SUITABLE WIKI EDITOR

The following technical considerations are recommended when choosing a wiki editor:

i) *familiarity*. Wiki editors may already be used within your teaching faculty, and may be attached to resources with which the students are already familiar, such as the *Blackboard* online learning environment (OLE) used by many educational institutions.

ii) *ease of deployment*. Many wiki tools require software to be made available, usually with an initially high (and then ongoing) level of computing support (installation and management of these online resources is likely to involve experience of network administration, as well as knowledge of various coding scripts). If there isn't a system in place within your institution, can you implement one yourself, can you access one online, or are there staff and resources available to help?

iii) *control over access*. What level of access exists to the resource, and who is able to edit it? Some wiki tools can be run within a closed network (such as a computer lab or university intranet), whilst others are more accessible to the outside world through the internet. Consideration needs to be given to who can read the entries, and also who has access to the editable resource.

iv) *ability to track entries according to user, and ability to save historical changes*. With a multi-user resource, pages created are by nature open to alteration by individuals other than the original creator. It is possible that pages could be altered inappropriately (either by accident, or intent), and an ability to view which individual created what changes, as well as the ability to revert to historic versions of the page may be useful. Similarly, being able to examine what has historically been saved may also be useful in the case of student complaints about work going missing, and being able to verify whether work was actually done by a student. If these are likely to be problems (especially if the work is being formally assessed), it is worth checking whether a resource allows any user to access and remove historic versions of pages, and whether this ability can be limited to individuals with administrator privileges. Furthermore, the ability to track an individual's entries may be important if the work is to be graded, although it is perhaps advisable to mark the work of the students in clearly-defined groups rather than as individuals.

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SUPPLEMENTARY MATERIAL

Supplementary Material 1: Outline practical sheet

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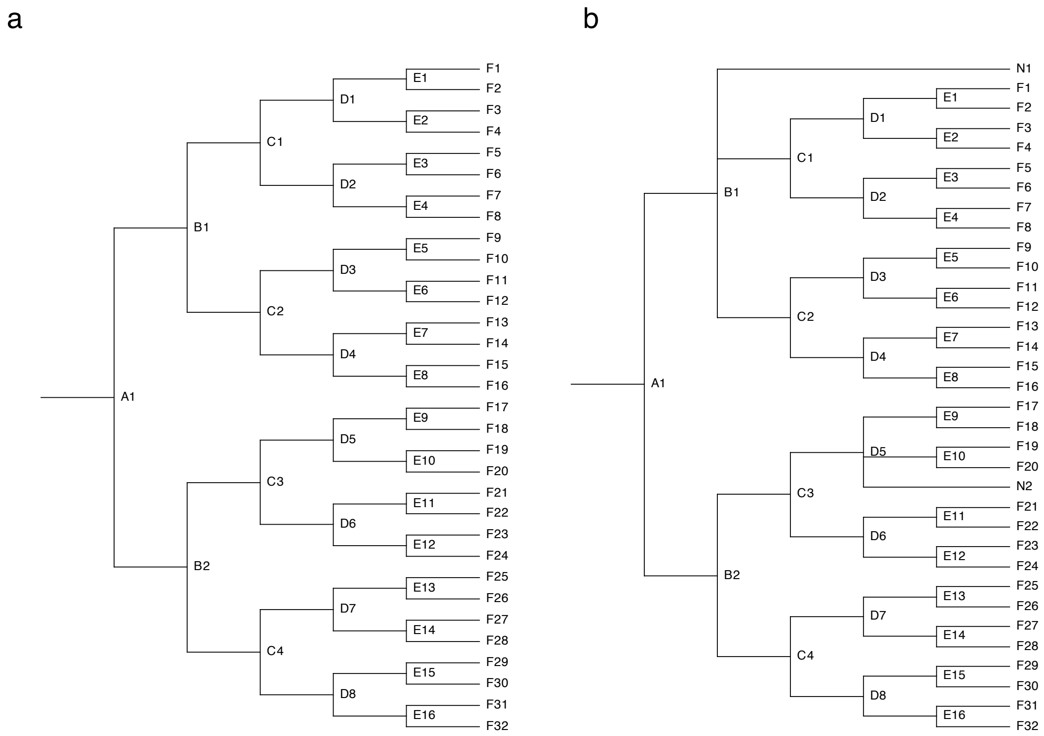
FIGURE LEGENDS

Figure 1: class splitting structure: *a*) simple scheme for class with 32 students; *b*) suggested instructor additions (N1 and N2) to demonstrate persistence of taxa. Figures drawn using *Treeview X* (Page 1996).



SUPPLEMENTARY MATERIAL FOLLOWS

NAME______________________________ DATE_________________________________

[redacted] TAXON	CLIMATE maritime climate – temperate, but prone to heavy rain and hurricanes during storm season
B 1	MORPHOLOGY waterproof scales, and spines for gripping onto surfaces in high winds REPRODUCTIVE SYSTEM gives birth to live young, who remain with parent until end of juvenile stage
C 2	TAXON NAME snike PRINCIPAL HABITAT temperate rainforest MORPHOLOGY long tail for grasping onto branches, with elongated barbs
D 3	TAXON NAME cryptic snike FOOD carnivorous: sit-and-wait predator MORPHOLOGY camouflage/cryptic colouration and body shape, to blend in with background vegetation BEHAVIOUR hangs motionless from tree by tail next to foraging sites of its prey with forelimbs stretched out – grabs for prey when it gets close enough
E 5	TAXON NAME screaming cryptic snike SENSORY SYSTEMS visual predator: stereo colour vision, ranging from red through to ultraviolet PREDATOR AVOIDANCE principal predator is a bat – when attacked, makes a high-pitched scream that temporarily deafens the predator
F 9	SPECIES NAME gliding snike MORPHOLOGY flaps of skin under forelimbs BEHAVIOUR releases grip on tree if attacked by predator, and is able to direct falling using flaps of skin

SKETCH YOUR ORGANISM ON A SEPARATE SHEET